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FINAL TECHNICAL REPORT

PROJECT A-1621

STUDY OF USGS/NASA LAND USE CLASSIFICATION SYSTEM

**By
G. William Spann**

**Prepared for
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama**

March 1975

1975



**ENGINEERING EXPERIMENT STATION
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ABSTRACT

This report summarizes the results of a computer mapping project using LANDSAT data and the USGS/NASA land use classification system. During the computer mapping portion of the project, accuracies of 67% to 79% were achieved using Level II of the classification system and a 4,000 acre test site centered on Douglasville, Georgia. Analysis of response to a questionnaire circulated to actual and potential LANDSAT data users reveals several important findings:

- (1) There is a substantial desire for additional information related to LANDSAT capabilities.
- (2) A majority of the respondents feel computer mapping from LANDSAT data could aid present or future projects.
- (3) The costs of computer mapping are substantially less than those of other methods.

ACKNOWLEDGEMENTS

The author would like to thank all of those who were kind enough to share information that made this report possible - respondents to the questionnaire. Aid was also received from the Georgia Department of Natural Resources and the Douglas County Planning Office for carrying out portions of this study. Mr. Nick Faust, who coauthored the interim report, also played a significant role in the completion of this project.

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I. INTRODUCTION

This is the second report prepared under this contract. It summarizes the results of the entire twelve month effort; however, the emphasis is placed on the last two program objectives. These are:

- (1) An identification of user requirements in land use mapping projects, and
- (2) A cost-effectiveness evaluation of land use mapping via computer processing of LANDSAT (formerly Earth Resources Technology Satellite) data.

The first objective - the evaluation of the compatibility of the USGS/ NASA land use classification system with automatic processing techniques applied to LANDSAT data - was covered in detail in the previous report. It is not intended that this report duplicate the information contained therein, but a summary of the interim report will be given in Section II of this report. For a complete picture of the project results, both reports should be reviewed.

From the outset this project has been user oriented. During the initial phases of the study, the Georgia Department of Natural Resources and the Douglas County Planning Office were consulted on several occasions. After completion of the land use mapping effort and the interim report, a presentation was given at EES which was attended by personnel from several state agencies. Finally, approximately 200 questionnaires were distributed along with copies of the interim report, and user evaluations were solicited. The questionnaire and briefing are covered in Section III.

Analyses of the user responses are given in Sections IV and V. They are evaluated according to operational requirements of potential users. Cost effectiveness measures are also derived from user supplied data and from EES cost estimates.

Finally the complete project is summarized in Section VI. From the results obtained in this project it appears that computer land use analyses from LANDSAT data have substantial benefits to some users. There are other users for whom these data are useful but the data are not sufficient by themselves. Considering relative costs, computer mapping from LANDSAT data is the only feasible method of carrying out some projects.

II. SUMMARY OF INTERIM REPORT

Introduction

From the results of several previous investigations by various groups it is obvious that land use can be mapped via computer processing of LANDSAT (formerly Earth Resources Technology Satellite) data [1,2,3,4]. However, many of the projects carried out to date have been special purpose in the sense that they were either very specifically directed toward one goal, or alternatively any land use categories that fell out were mapped. In one project, for example, a land use map of Milwaukee County was prepared which had five categories of water displayed. None of the above is meant to criticize the results of previous studies; however, it is intended to point out the lack of uniformity resulting from many previous land use investigations using computer processing of LANDSAT data.

There is at the present time intense interest in and support for enactment of a national land use bill. Should passage of this bill eventually take place, there is considerable merit in using a national land use classification scheme for any mapping carried out under this proposed legislation. One such system has been proposed by James R. Anderson, et al., specifically for use with remote sensor data [5]. The categories of land use proposed are given in Figure 1. As can be seen there are two levels of classification with Level II being a finer categorization of the Level I land use classes.

As stated in the publication, Level I classifications were derived so that the source of information could be "satellite imagery, with very little supplemental information." The sources of information required for Level II were expected to be "high-altitude and satellite imagery combined with topographic maps." Several investigations have shown, however, that it is possible to map many categories in Level II directly from the LANDSAT data tapes (with appropriate ground truth information). Due to the varied nature of these investigations, it is difficult to identify all of the Level II categories which can or can not be mapped utilizing computer processing of LANDSAT data.

Land-Use Classification System for Use With Remote Sensor Data

<i>Level I</i>	<i>Level II</i>
01. Urban and Built-up Land.	01. Residential. 02. Commercial and services. 03. Industrial. 04. Extractive. 05. Transportation, Communications, and Utilities. 06. Institutional. 07. Strip and Clustered Settlement. 08. Mixed. 09. Open and Other.
02. Agricultural Land.	01. Cropland and Pasture. 02. Orchards, Groves, Bush Fruits, Vineyards, and Horticultural Areas. 03. Feeding Operations. 04. Other.
03. Rangeland.	01. Grass. 02. Savannas (Palmetto Prairies). 03. Chaparral. 04. Desert Shrub.
04. Forest Land.	01. Deciduous. 02. Evergreen (Coniferous and Other). 03. Mixed.
05. Water.	01. Streams and Waterways. 02. Lakes. 03. Reservoirs. 04. Bays and Estuaries. 05. Other.
06. Nonforested Wetland.	01. Vegetated. 02. Bare.
07. Barren Land.	01. Salt Flats. 02. Beaches. 03. Sand Other Than Beaches. 04. Bare Exposed Rock. 05. Other.
08. Tundra.	01. Tundra.
09. Permanent Snow and Icefields.	01. Permanent Snow and Icefields.

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Figure 1. USGS/NASA Land-Use Classification System.

In order to provide a consistent basis for discussing land use mapping via LANDSAT, the present program was instituted. The general objective of this program is, thus, a determination of the extent to which the USGS/NASA land use classification system is compatible with the computer processing techniques employed for land use mapping from LANDSAT data.

One of the current problems facing land use planners is lack of a common vocabulary with the specialists who process remote sensing data. The USGS/NASA land use classification system is an attempt to bridge this communication gap. However, there is still some confusion because automatic processing is capable of identifying more categories than those contained in Level I but less categories than are contained in Level II. This study provides information that makes it possible to specify those categories of land use which can be identified using LANDSAT data. This should provide a common ground on which land use planners and processing specialists can begin working together to solve land use problems.

The Georgia Department of Natural Resources (DNR) also participated in the study by providing inputs on the applicability of these results to operational planning agencies. Since Douglas County was chosen as the test site for this project, the Douglas County Planning Office provided inputs necessary to the study.

In succeeding paragraphs we will discuss the results obtained in the first portion of this project. These include the reasons for selecting Douglas County, the actual mapping project, accuracy evaluation, and some problems that might be faced in carrying out an operational project using these techniques. As mentioned previously, this only summarizes the interim report; more complete detail is to be found in the report itself.

Reasons for Choosing Douglas County Test Site

Douglas County is at an earlier stage in its development than many counties in the Metro Atlanta area. However, several recent and pending events promise to accelerate rapidly the growth of this area. Of necessity this means that land use patterns are changing rapidly and will continue to do so in the future. It is important, therefore, in this county that there

be planning for the impacts on land use which will occur. For these reasons, Georgia DNR selected Douglas County as an appropriate test site.

The single major cause of the county's present rapid growth in residential and other areas is the recent completion of Interstate 20 into the county. This provides relatively easy access to the area from the center of Atlanta. As usually happens with the opening of a new transportation corridor, many families have chosen to locate along I-20 in Douglas County. Since I-20 presently ends within the county, many people who might otherwise live further from the center of Atlanta, probably locate in Douglas County. For whatever reasons, the recent completion of I-20 into the county seems to have accelerated the growth of the county.

Pending events could have a much greater impact on Douglas County than simple outward growth from Atlanta. A site in the north portion of Douglas County is one of the proposed locations for a second Atlanta airport. If this should occur, many new industrial, commercial, and residential areas will open up within the county. One logical transportation corridor to the airport site would be a limited access highway originating at I-20 in Douglas County and terminating at the new airport. This would further increase pressures for development in Douglas County.

A west Georgia tollway has been proposed to link Chattanooga with Tallahassee. Should this road be built it would pass through or near the western portion of Douglas County. This major North-South transportation route would certainly impact the development of the west Georgia area, including the Douglas County area.

The present rapid growth and the potential for continued expansion in Douglas County is clearly evident. For the Georgia Department of Natural Resources, then, the results of this study provided a base of information on the land use in Douglas County for 1972. It will enable DNR to monitor progress and update this base as appropriate to take into account any of the events mentioned here. If neither of the proposed projects occur, growth within the county will certainly continue, but at a slower rate.

Douglas County Land Use Mapping

The LANDSAT mapping discussed in this report was accomplished using the Algorithm Simulation Test and Evaluation Program (ASTEP) implemented on a Univac 1108 at Georgia Tech. This program, which was originally written for NASA/JSC has been extensively modified by EES personnel to meet the needs of this and other mapping projects. As currently implemented at Georgia Tech, ASTEP (1) uses a maximum likelihood algorithm for pattern classification, (2) has been modified for automatic scaling specifically for LANDSAT remote sensing applications, (3) has the capability for rotation of the data to true north and overlaying a geographic coordinate system, and (4) contains provisions for both feature selection based upon a correlation matrix eigenvector transformation and for change-detection pattern recognition.

The maximum likelihood algorithm is based upon Baye's formula^{*} from classical statistics and an assumption of multivariate, normal (Gaussian) probability distributions. (This assumption is usually adequately satisfied in practice, except where multimodal statistics exist.) The algorithm allows supervised classification with greater accuracy than the clustering algorithms if appropriate training data sets are available. Excluding the training time for the classifier, the maximum likelihood approach generally uses less computer time than the clustering method for a specific data set. In addition to the classification algorithm, the program ASTEP contains subroutines which provide the operator with useful statistics, cluster data, and level slices for intelligent use of the program for classification of LANDSAT remote sensor data.

Software for operation with a Tektronix Cathode Ray Tube plotter has been integrated into the ASTEP program package. This allows the user to immediately display and generate a hard copy of a 2 or 3 dimensional plot of the spectral data for use in evaluating the separability of data classes. A 2 dimensional histogram of the data may also be selected. By viewing the actual data in 2 or 3 dimensions the user can visually decide if two classes

^{*}This allows minimization of the "total expected loss" by individually minimizing the "a posteriori conditional risks."

overlap in spectral space. This overlap is often the cause of misclassification.

Land use maps have been prepared for that portion of Douglas County which includes Douglasville and the majority of the developed area in the county. The LANDSAT scene processed was that of October 15, 1972. NASA high altitude photography, also taken in October 1972, was obtained from the EROS Data Center for use in the accuracy evaluations. Supplemental data in the form of field surveys and low altitude oblique photography were also used.

A "quick look" accuracy evaluation was made to ensure that the land use categories identified from LANDSAT were largely correct. This was accomplished by enlarging the high altitude photography to the scale of the LANDSAT printout - 1:24,000. A visual comparison of the two products then determined that the results were generally correct with the exceptions noted later in this section.

A pixel-by-pixel accuracy evaluation was completed for a portion of the area. This was accomplished in the following manner: a clear overlay of the 1:24,000 enlargement was prepared as a land use map of the area. Land use was classified according to Level II of the USGS/NASA land use classification system. Approximately 4000 acres have been compared with LANDSAT data to provide quantitative accuracy results for each land use category. These results are based on supervised classification techniques using maximum likelihood decision criteria.

As stated previously, it is possible to produce land use maps with a high degree of accuracy using the categories of Level I of the USGS/NASA classification scheme and automatic processing techniques. The categories which can be found and mapped in our test area include: urban and built-up, agricultural land, range land, forest land, water, and barren land. The accuracy of a Level I classification approaches 100%.

The Level II categories which can be identified and mapped include: residential, commercial and services, industrial, extractive, strip and clustered settlement, and open and other; cropland and pasture; deciduous, evergreen, and mixed; streams and waterways, lakes, and reservoir; and bare

exposed rock. The categories of Level II present more problems in terms of their unique identification than do the categories in Level I. This is related, in general, to the fact that LANDSAT measures land cover and we mapped land use. These problems, however, will be discussed in more detail later. First we will discuss processing results specifically related to each category above.

Residential. We have been successful in identifying both low and medium density residential as separate categories or as one category. However, we have not found one single category that we could call residential. Multi-family housing, for example, has the same signature as industrial areas in many cases. Hence it could not be completely separated out to be included with residential. There are problems also with identifying heavily wooded subdivisions as residential.

Commercial and Services. Commercial areas, especially those with large parking lots, are readily identifiable. There is good separation between the signatures of commercial and industrial areas. However, there is difficulty in separating commercial and services from institutional which, in fact, often performs some commercial service. An office park does not necessarily look different from an institution of higher learning, for example.

Industrial. The industrial category is reasonably well differentiated from commercial and transportation areas except for transportation/warehousing areas. There are some misclassifications due to large storage areas which resemble manufacturing plants. As was mentioned previously, multifamily housing often has signatures similar to industrial complexes.

Extractive. The only forms of extractive land in the present study area are large stone quarries from which road building materials are derived. These areas are generally identifiable from their high reflectance, but can be confused with concrete parking lots or airport runways.

Strip and Clustered Settlement. This category is identifiable in the processed data but more from its shape than its spectral characteristics.

Often this category will contain a combination of commercial, multifamily housing, and transportation.

Open and Other. In an urban/suburban environment this category is most often a well-kept grassy area such as a park, golf course, or cemetery. These areas are identifiable with a high degree of accuracy.

Cropland and Pasture. In the October 15, 1972 scene most of the crops have been harvested. Thus there usually remains only oat or corn stubble, or possibly bare ground where the crops had been planted. Pastures, however, are readily identifiable including some areas which are being grazed after harvesting. The signature for pasture is similar to the open grass areas in more urbanized areas.

Deciduous, Evergreen, and Mixed Forests. Deciduous forests are easily separable from evergreen forests, particularly in October when leaves are turning on deciduous. Mixed forest sometimes tends to be dominated by one category or the other in the classification. However, areas of mixed forest are separable in other instances from either deciduous or evergreen.

Streams and Waterways, Lakes, and Reservoirs. All of these Level II categories tend to be classified into a single category - water. Streams (large) and waterways can be separated from lakes and reservoirs generally on the basis of shape. However, supplementary data are often required to differentiate lakes from reservoirs.

Bare Exposed Rock. No bare exposed rock exists in the areas currently classified in Douglas County. However, from previous studies in the Stone Mountain, Georgia area, it is known that this category can be recognized.

Most of the inaccuracies in classification above relate to trying to classify land use from land cover. Planners in general, and the Georgia Department of Natural Resources in particular, are interested in land use information. A heavily wooded residential area with large lots, and hence much space between houses, should be classified as residential from a planner's point of view. However, from the LANDSAT data it is difficult to classify all of this area into one category which could be called residential.

The tendency is to have two or more categories representing forest, grass and housing.

Other examples of this problem are found in the case of airports. One cannot uniquely define a LANDSAT signature for airports. The area occupied by an airport consists of several different types of land use including runways and taxiways, buildings, and service/maintenance areas. These and other issues are discussed in more detail later.

Accuracy Evaluation

Preliminary results of our accuracy evaluation of the computer generated land use map are given in this section. For the purposes of this report only about 10% of the total area was evaluated. This included about 4000 acres centered on Douglasville - probably the least accurate area from a classification standpoint.

The photointerpretation was assumed to be correct. Both NASA high altitude photographs and low altitude observations and field checks were used in arriving at the "correct" classifications. However, the results may be subject to some revision as the study proceeds.

The overall accuracy of the computer-generated map was 67% as shown in Table I. Accuracies ranged from 87% in the residential category to only 26% for the open category. This low figure results, in part, from an inadequate sample containing open areas and the diverse definition given to open areas.

An area of substantial misclassification was in the three forest categories—deciduous, evergreen, and mixed. Had there been only one category into which all forest areas were classified, the overall accuracy would have risen to 79%. Land use maps generated by and for planning agencies typically have only one category for forest, and this may be a transparent color overlaying all other categories.

While this accuracy is certainly not as high as is desired for most land use maps, the results compare favorably with published results of manual photointerpretation of high altitude photography. In a recent report by Paul L. Vegas [6] at NASA/NSTL, an overall accuracy of 84% was obtained using manual interpretation of NASA high altitude photography. The categories used

	Res.	Com.	Ind.	Extr.	Trans.	Open	Crops	Decid.	Ever.	Mixed	Water	% Accuracy
Residential	1056	29	5	0	36	2	39	7	30	11	0	87
Commercial	67	178	36	2	11	6	6		2			58
Industrial												-
Extractive		7	3	16								62
Transportation	56	2			43							43
Open	17				3	7						26
Crops	50						105	2	42	3		52
Deciduous	70				2	1		298	34	145		54
Evergreen	45				1			7	190	53		64
Mixed	126	1						57	88	401		60
Water	1				1		1	1			14	78
TOTAL												67
TOTAL (with only 1 forest category)												79

Correct classifications are indicated along the diagonal, e.g., 1056 pixels were correctly classified as residential but 29 pixels which should have been classified residential were classified as commercial.

TABLE 1. Accuracy of Computer Generated Land-Use Map from LANDSAT Data.
(Numbers in Matrix Indicate Number of LANDSAT Pixels.)

in the classification were somewhat different than those for Level II categories. However, there is enough similarity to warrant comparison.

Most of the area (approximately 95%) of Georgia is rural. Since the accuracy of this technique is highest in rural areas, it is estimated that 95% of the area of Georgia could be mapped with accuracies in the 80% to 90% range.

Problems Relative to LANDSAT Processing Using USCS/NASA Land Use Classification System

Some categories of land use are not obtainable from any remote sensor - LANDSAT or high or low altitude photography. Consider the categories of transportation, communications and utilities. From LANDSAT or from photography, an airport will not look similar to a rail switching yard, let alone a communications complex or a utility. A human interpreter can possibly make allowances because of a priori knowledge and classify all of the above into a single category. However, it is not possible for even a human interpreter to exactly define the boundaries of the above unless they are fenced in at the boundary or there is a change of vegetation at the boundary.

Many other categories share this problem. It can be difficult to discern the boundary of a park, for example, from either photographs or LANDSAT computer maps. Clearly supplemental information is required to make a land use map which accurately reflects parameters necessary for intelligent planning.

Part of the problem with an airport, for example, is that there are several types of land cover within the boundary. At the Hartsfield International Airport in Atlanta, there are these categories of land cover: bare ground, concrete, asphalt, large buildings, trees, and grass. On a computer classification map these areas are likely to classify with industrial, commercial, forest, and open and other.

The preceding paragraph outlines a problem which is much more general than just defining the boundaries of a particular category such as transportation/airport. This is the problem of observing land cover and classifying

land use. It is apparent in several categories of land use. Residential areas, for example, range from apartment complexes to cluster/condominium homes to single family detached residences with lot sizes from 1/4 acre to 10-15 acres - even in urban areas. It appears that planners generally would like for all of these to be categorized as residential or possibly multi-family/single family residential.

This has proved impossible so far. The difficulties with multifamily have been discussed previously. Contextual information (or a priori knowledge) however, often allows one to differentiate between industrial areas and multifamily residences. With very low density residential areas, particularly those which are heavily wooded, there are likely to be several categories on a computer generated LANDSAT map. The areas occupied by the houses/lawns/driveways will probably be classified in a category which includes higher density single family residential. The forested areas in between houses, however, are likely to classify as deciduous, evergreen, or mixed. Since these areas are neither open/other nor forests in the true sense of the word, they should be classified residential. (Indeed there is no category for forest in class 01.) This has proved difficult so far, because to classify these areas accurately would require a decision algorithm incorporating spatial/contextual information.

Another problem arises in a test area such as this which includes both urban and rural land use. Open areas in an urban setting are usually golf courses, parks or other grassy areas. The signature for this category of land use is virtually identical to the signature for pastures - a rural land use. While each of these categories can be identified in its proper setting, there are no unique signatures which apply to these categories separately.

There are other problems associated with measuring land cover and mapping land use but these generally are similar to the above. It seems that one additional question needs to be addressed in order to cope with these problems: What is the minimum complement of additional information that will enable one to produce accurate land use maps?

Supplemental Mapping Information

The most logical place to start looking for additional information is on USGS 7-1/2 minute quadrangle maps. These maps suffer from infrequent updating and incomplete coverage, but this need not be a severe handicap. Some of the more difficult categories of land use are semi-permanent—transportation facilities, for example. Other useful information of a semi-permanent nature is also available including parks, schools, churches, cemeteries, hospitals, prisons, etc. One could start the mapping project with these land uses on a base map and concentrate the LANDSAT data processing on other categories such as residential, commercial and industrial. These are the categories that change rapidly, particularly in a fast-growing urban/suburban area. In contrast, the boundaries of parks, airports, etc., change slowly, if at all, and these boundaries are shown on the USGS maps.

Another source of useful information is visual examination of the area. The traditional windshield survey, however, is quite slow and tedious. A more efficient method for these examinations seems to be low altitude surveillance from light aircraft. In our current project the two investigators spent a major portion of one day visiting approximately two dozen sites in Douglas County and photographing these areas. A return visit was made by light aircraft and the same sites, plus many others, were photographed in less than 1 hour flying time and less than two hours total time.

The above are some possible sources of supplemental information which would be useful to a LANDSAT computer mapping project. In those operational cases where they are employed, there seems to be no system for carrying out these tasks in an efficient and timely manner. It seems, therefore, that work to devise and test such a system would be beneficial to those who require land use information on a regular basis.

Summary and Conclusions

This study has attempted to provide some "standardization" to the mapping of land use via computer processing of LANDSAT data. It has pointed out areas where such mapping appears practical and other areas where further research is required. While the land use categories used do not necessarily reflect those desired by various groups, they are probably representative of such categories.

Results of this project indicate particular applicability to non-urban areas and to those projects requiring fewer land use categories than those represented by the Level II classification used here. Examples of such applications might include transportation planning models and hydrologic models as well as generalized land use maps.

III. SOLICITATION OF USER EVALUATIONS

The primary method by which user evaluations were sought was a questionnaire developed for this purpose. A copy of this questionnaire is included as Figure 2. The questionnaire was designed to derive both qualitative and quantitative data so that both operational requirements and cost effectiveness could be measured.

Several questions in the questionnaire are devoted to measuring each of the objectives mentioned previously. The questionnaire was structured as follows: several general questions (1-5) were asked to determine the extent of familiarity with remote sensing data and the primary orientation of the user with respect to urban/rural settings. These items are thought to be significant because they indicate what the users might be comparing LANDSAT mapping with.

A second group of questions (6-10) was designed to derive measures of cost effectiveness for computer mapping with LANDSAT data. Of necessity these questions request a combination of quantitative data and opinion. In effect we are only able to measure the perceived effectiveness of LANDSAT data. It would be prohibitively expensive to measure true effectiveness, if indeed it could be done. The costs reported by users for other mapping projects can be assumed to be good data. These can be compared to the projected costs of LANDSAT computer mapping project.

Finally, several questions (11-16) dealing with operational requirements and future mapping efforts were included. In addition to identifying user requirements, these responses identify those users who might be considering the use of LANDSAT data in later projects. It provides another measure of the perceived usefulness of LANDSAT data to operational problems.

Obviously a questionnaire such as that described above is useless if the respondent is unfamiliar with LANDSAT and some of its capabilities. The selection of agencies/individuals was thus carefully considered. Two major distribution efforts were decided upon. First, approximately 150 questionnaires were distributed at the ASP-sponsored Remote Sensing Symposium held in Athens, Georgia on January 28-30, 1975. Copies of the interim report on this project were also provided all attendees, and the results of the

Figure 2.

EES - NASA/MSFC REMOTE SENSING QUESTIONNAIRE

This questionnaire is designed to gather information to be used in a cost effectiveness evaluation of land use/land cover mapping via computer processing of LANDSAT (formerly Earth Resources Technology Satellite) computer compatible tapes. The project is being performed by the Engineering Experiment Station (EES), Georgia Institute of Technology for NASA/Marshall Space Flight Center. Your cooperation in helping with this evaluation will be greatly appreciated.

If you are unfamiliar with computer mapping from LANDSAT data, it may be beneficial to delay completing this questionnaire until after the conference. There is also information available at the Engineering Experiment Station display which might prove helpful.

Please return the questionnaire to G. William Spann at the conference or in the attached envelope. If you would like a copy of the report when it is complete, place a check in the box beside your name.

Name _____ ☐

Affiliation _____

Address _____

Phone Number _____

1. What is your primary area of interest in remote sensing? Land Use _____
Pollution Monitoring and Control _____ Impact Statements _____ Resource Management _____
Transportation _____ Other (Please Specify) _____
2. Do you presently use remote sensing data in your work? _____
3. If so, what types of data? B&W Film _____ Color Film _____ Color Infrared Film _____
Thermal Imagery _____ Radar Imagery _____ Multispectral Scanner Data _____
4. Which types of data would you like to have available to work with? B&W Film _____
Color Film _____ Color Infrared Film _____ Thermal Imagery _____ Radar Imagery _____
Multispectral Scanner Data _____
5. Are you primarily concerned with: urban/suburban areas _____ rural areas _____
both _____?
6. Have you used any LANDSAT data in your work? _____ If so, which type? B&W Photographs _____
Infrared Color Composites _____ Computer Compatible Tapes _____
7. How do you rate the usefulness of the LANDSAT products in your work? (Good, Fair, Poor)

	Rural Areas	Urban/Suburban Areas
B&W	_____	_____
Infrared Color Composites	_____	_____
Computer Compatible Tapes	_____	_____

Figure 2. (Continued)

8. Have you been associated with any recent efforts at land use/land cover mapping? ____ If so, please describe briefly. _____

9. What do you estimate to be the accuracy of the land use data obtained on this project? _____
10. What was the approximate total cost and approximate total area involved in the project? _____

11. What scale(s) do you prefer for the data? What scale(s) do you prefer for the final map(s)? Please explain. _____

12. Have you used the USGS Geologic Circular 671 land use classification system? ____ If so, did you encounter any difficulties? Please explain. _____

13. Would you have any specific changes to suggest to the classification system? _____

14. Do you anticipate any land use/land cover mapping efforts in the near future? ____ If so, please describe briefly. _____

15. What data sources do you anticipate using to gather this information? _____

16. Do you feel that computer mapping from LANDSAT data could be of any benefit in this project? ____ If so, how much? Relatively little ____ Some ____
Substantial ____

OTHER COMMENTS

Douglas County computer processing effort were displayed along with an aerial photograph of the same area. This group of respondent . then, can be assumed to have a reasonable knowledge of the capabilities for computer mapping with LANDSAT data.

There were a substantial number of potentially interested users who did not attend the symposium, however. In order to achieve a meaningful response in a reasonable amount of time, a mail distribution was decided upon. This mailing was generally limited to those individuals/agencies in Georgia known to have had some introduction to LANDSAT and its capabilities. Approximately 30 questionnaires were distributed by mail.

By these two methods a good sample of users were identified and questioned. Responses came generally from the southeast, but some questionnaires were received from as far away as Indiana, California, and Washington, D. C.

Responses to the questionnaire varied widely, especially for some questions such as 11-13. An attempt is made, however, in the next two sections to analyze all responses and aggregate the data in a meaningful way.

IV. ANALYSIS OF USER RESPONSE - COST EFFECTIVENESS

Because of the wide variations in responses received as a result of the questionnaire, there is no consistent way to aggregate all of the data. However, all of the responses were considered in preparing this section and the next. Wherever possible, the data are aggregated into meaningful categories. In addition, some responses were selected to quote directly.

As mentioned previously, the first five questions were intended to derive general information about the users responding to the survey. In order to introduce the background and applications of some of the respondents, these data are tabulated here (numbers indicate positive responses).

What is your primary area of interest in remote sensing? Land Use 29
Pollution Monitoring and Control 7 Impact Statements 10 Resource
Management 20 Transportation 9 Other (Please Specify) _____

Do you presently use remote sensing data in your work? YES-32 NO-8

If so, what types of data? B&W Film 30 Color Film 24 Color Infrared
Film 33 Thermal Imagery 8 Radar Imagery 5 Multispectral Scanner
Data 15

Which types of data would you like to have available to work with? B&W Film
27 Color Film 26 Color Infrared Film 34 Thermal Imagery 19 Radar
Imagery 14 Multispectral Scanner Data 25

Are you primarily concerned with: urban/suburban areas 0 rural areas 11
both 29

From analysis of the above it is obvious that the majority of the respondents are interested in land use and resource management, two closely related areas. In addition to the categories specified, several respondents had other interests. Among those listed were: resource appraisal, urban change, geology, hydrology, wetlands research, plant stress/disease, soil surveys, and geobotanical studies. The predominance of respondents who indicated land use as an area of primary interest demonstrates the need for information such as that derived from this project.

It is not surprising that most of the respondents have used remote sensing in their work. Aerial photography is readily available as a result

of numerous private and public mapping programs as well as from NASA aircraft and satellite missions. However, only slightly more than half of those returning questionnaires had used LANDSAT data in their work (see below).

The most popular forms for remote sensing data were film types - black and white, color, and color infrared. There were also a number of respondents who used and/or preferred thermal imagery, radar imagery and multispectral scanner data.

All of the respondents were either interested in rural areas only or both urban/suburban areas and rural areas. Urban/suburban areas were singled out by none of the respondents.

It appears then, that the composite respondent to the survey is interested in land use and/or resource management and has used remote sensing in his work. Most respondents have used and prefer to use photographic products but several have used multispectral scanner data. Rural areas or a combination of rural and urban/suburban areas are of interest to all respondents. This is not too surprising since rural areas comprise about 95% of all land in the U. S.

Questions 6 and 7 were designed to measure the familiarity of users with LANDSAT data and to evaluate their experience in using LANDSAT data of various types. However, it appears that we have in many instances measured the perceived usefulness of LANDSAT data rather than its actual usefulness in operational projects. We must draw this conclusion because a number of respondents who had not used LANDSAT data rated its usefulness in question 7. The results from all of the respondents are listed below.

Have you used any LANDSAT data in your work? YES-28 If so, which type?
 B&W Photographs 18 Infrared Color Composites 20 Computer Compatible
 Tapes 8

How do you rate the usefulness of the LANDSAT products in your work? (Good, Fair, Poor)

	Rural Areas			Urban/Suburban Areas		
	(G)	(F)	(P)	(G)	(F)	(P)
B&W	12	7	4	4	5	6
Infrared Color Composites	15	5	3	7	7	2
Computer Compatible Tapes	8	2	3	6	0	4

Of those who rated the usefulness of LANDSAT data, most were familiar with photographic products only and most had experience only with rural areas. Despite some apparent inconsistencies in the data, the majority of the respondents to this question think LANDSAT data are useful and that good results can be obtained from one or more LANDSAT products.

If only those respondents who have actually worked with LANDSAT data are included, the results are somewhat more positive. This is particularly true in the case of CCT data where all but one of the "poor" responses are eliminated and only two "fair" responses remain - the remainder of the responses indicating "good" results. This indicates that CCT data are highly regarded by those who have used them, but few respondents have actually employed these data in their projects. Results from only those individuals who have used LANDSAT data are shown below.

How do you rate the usefulness of the LANDSAT products in your work? (Good, Fair, Poor)

	Rural Areas			Urban/Suburban Areas		
	(G)	(F)	(P)	(G)	(F)	(P)
B&W	8	4	2	2	5	4
Infrared Color Composites	13	4	1	5	5	2
Computer Compatible Tapes	4	2	0	3	0	1

Questions 8, 9 and 10 related directly to costs incurred in other land use/land cover mapping projects. Because of highly varied responses, no complete tabulations are made. However, we have attempted to select the most representative data for further analysis.

Most of the respondents to the questionnaire had been involved in land mapping projects of some type or were presently involved in one. Estimated accuracies ranged from "highly generalized and highly questionable" to "completely accurate to less than one acre." Table 11 was prepared from only those responses which met the following criteria: accuracy, cost/area and scale were all included in the responses, and there were no inconsistencies in the data.

The objectives of each mapping project were different and, therefore, so were the scales, data sources, and other parameters. The accuracies

TABLE 1'
USER ESTIMATES OF ACCURACY AND COST FOR
OTHER MAPPING PROJECTS

Scale (s)*	Accuracy	Total Area	Cost/Sq. Mi.
1:400	95%	1250 sq. mi.	\$ 1.08
1:24,000/1:60,000/1:125,000	80%	300 sq. mi.	60.00
1:60,000	85%	100 sq. mi.	100.00
1:24,000/1:48,000	20%	180 sq. mi.	55.56
1:250,000	85%	500 sq. mi.	10.00
1:12,000, 1:24,000	100%	469 sq. mi.	149.00

*Multiple scales reported by some users without further explanation.

attained, however, were in the range of the accuracy obtained from computer mapping with LANDSAT data. Also, the scales employed by several individuals were the same as the 1:24,000 used in the computer mapping.

The costs involved in these projects, however, were generally much higher than the costs estimated for land mapping via computer processing of LANDSAT data. Based on several studies at EES, an operational mapping project involving a substantial area (> 100 sq. mi.) would cost on the order of \$1 to \$3 per square mile depending on the exact requirements of the project. In only one case were the mapping costs in this range. The next lowest figure was \$10 per square mile - almost certainly an upper limit on any computer mapping costs using LANDSAT data.

Other estimates of the costs of land use mapping from LANDSAT data are contained in the published literature. Simpson and Lindgren [7] of Dartmouth College have estimated a cost of \$28,000 for a "state sized" area. If the state is New Hampshire (where Dartmouth is located), this is approximately \$3.00 per square mile.

Jayroe, Larsen, and Campbell [8] of NASA/MSFC have also published cost estimates of just the computer time necessary for large-scale mapping from LANDSAT CCT's. Their estimates range from \$.06-\$.13 per square mile for computer time only. Also they state that it is based on use of an

IBM 7094 at \$60 per hour. At EES estimates of computer time only range from \$.40-\$.50 per square mile, but these are based on a Univac 1108 at \$400 per hour. Also the EES estimates include signature acquisition time, whereas it is unclear whether or not the MSFC estimates include this time.

In a recent study at NASA/National Space Technology Laboratories, Dr. Armond T. Joyce [9] has compiled cost data for computer classification of one LANDSAT scene (about 13,000 square miles). Naturally these costs would change if more or less than one scene were processed. Dr. Joyce estimates that the costs of producing a computer classification stored on magnetic tape (i.e., for input to a computer model) are from \$.54-\$.69 per square mile. To obtain a color coded hard copy output would cost about \$.04 per square mile at a scale of 1:250,000. At a scale of 1:62,500 the costs would approximate \$.61 per square mile. Thus, depending on a number of factors, costs in the range of \$.58 to \$1.30 per square mile might be expected for processing one complete LANDSAT scene.

The wide variation in estimates for computer mapping costs apparently are the results of what is included in the effort. EES estimates, for example, include ground truth evaluation, signature acquisition, and computer processing. The MSFC estimates are for computer time only, and it is not known what is included in the estimates from Simpson and Lindgren. It is thought that the EES estimates are probably an upper limit on computer mapping costs—other estimates are for lower costs.

V. ANALYSIS OF USER RESPONSE - OPERATIONAL REQUIREMENTS

Response to questions 11-13 was somewhat disappointing. Few respondents answered questions 12 and 13, and those who did gave very general answers. The situation was somewhat better for question 11, but some difficulties were encountered here also.

As indicated in the previous section, there were a wide variety of preferred scales for data and for maps. Most respondents, however, indicated that standard USGS map scales were preferred including: 1:24,000, 1:62,500, 1:125,000, and 1:250,000. Scales as large as 1:400 and as small as 1:1,000,000 were also specified. In addition, some were only interested in aggregate land use data for input to computer models. For these users, scale was of no consequence since the desired product did not include maps.

Only twelve of the questionnaires indicated that use had been made of the proposed USGS/NASA land use classification system. Most of these users were satisfied with the system or the proposed modifications to the system. Of those who expressed dissatisfaction with the system, most wanted a level III, IV or finer breakdown included in the system. Other typical comments included, "I would like to see the same work done for more intense urban areas at a smaller scale," "The classification does not fit precisely the categories we find significant," and "This system is weak in several areas of resource classification."

None of those who objected to the USGS/NASA classification gave sufficient detail about proposed revisions to warrant inclusion here. Generally, the need was expressed for finer classification schemes that were in some way "standard."

Answers to the last three questions in the series were perhaps the most informative of all. Over 75% of those responding were involved in or anticipated some land mapping effort. This reflects actual needs for the type of data that could be supplied from computer processing of the LANDSAT data.

The data sources indicated by those involved in the above projects include virtually every imaginable source. Some of these were: windshield surveys, personal interviews, aerial photography, LANDSAT photographs,

Skylab photographs, and LANDSAT CCT's. Low altitude and/or high altitude aerial photography was mentioned by most respondents as the data source they were likely to use.

A significant percentage of the respondents reported that they thought computer mapping from LANDSAT data could benefit them in present or future projects. A number of those who responded negatively or did not respond either way indicated that they would like more information about LANDSAT and its capabilities. A tabulation of the responses to the last question is given below:

Do you feel that computer mapping from LANDSAT data could be of any benefit in this project? YES-21 If so, how much? Relatively little 2 Some 9 Substantial 10

The above tabulation of relative merit (question 16) includes only those respondents who answered positively. If someone indicated that computer mapping would be of no benefit, no rating was applied even though he may have checked "relatively little."

Considering the responses to this question as well as the responses to question 7, there is a high perceived usefulness for computer mapping using LANDSAT CCT's. However, there is also a strong need for additional education in its availability, applicability, and use. This was brought out here and in many of the comments listed at the end of the questionnaire.

One response to the questionnaire deserves a complete analysis. It probably represents "the future" of LANDSAT and similar earth-viewing satellites. The Georgia Department of Transportation (DOT) has been following the results of this project closely. Their application is ideally suited to computer mapping from LANDSAT data. Furthermore, this is the only feasible method of gathering the data from both a cost and timeliness standpoint.

Presently, the Georgia Department of Transportation and the University of Georgia are jointly developing a transportation planning land use simulation model which will allow the Department to examine the impact of transportation corridors upon land use, population, employment and housing on a

statewide basis. The model is being specifically designed to facilitate impact studies of alternative transportation corridors. A series of model runs may be used to estimate impacts over any highway length or corridor width.

The transportation planning land use model is an impact type, iterative, interactive land use simulation model. The model represents a series of self-contained, interrelated submodels. The submodels to be developed are employment, population, housing, land use, and transportation. This modular framework will make it possible to run the model with alternative forecasting techniques and alternative policy assumptions.

The project is divided into three phases. Presently it is in Phase I, which involves the development of the simulation model and its application to seventeen counties in Northeast Georgia (i.e., Newton, Morgan, Greene, Rockdale, Walton, Oconee, Gwinnett, Clarke, Oglethorpe, Barrow, Jackson, Madison, Gilbert, Hall, Banks, Franklin, and Hart). Allocations are made to the county and county census divisions based upon activity levels, land availability, accessibility, and attractions indices.

Population, housing, and employment are constrained to a large extent by the land use submodel in terms of the amount of developable land and the land absorption coefficients. Within their present framework, there is an inadequate supply of reliable land use data. Georgia DOT has only been able to collect those items related to a gross aggregation of soil characteristics, slope, vegetation (some), and a simple differentiation of urban areas and rural areas. Thus, in the land use equation system, they are forced to be very general because of the limited land use data. This indicates that there is a problem of manually collecting detailed, reliable land use data and managing these data for input into the modeling process.

In order to overcome some of the problems with manual methods of gathering land use data, the use of computer processing of LANDSAT data is envisioned. The use of LANDSAT data for the seventeen county test area will greatly aid modeling efforts by increasing the detail and accuracy of the land use data. Basically, what is desired from LANDSAT are data tables

using the Anderson classification (Level II) for the study area aggregated by county census division. In the near future Georgia DOT envisions dealing with the land use data on about an acre basis. DOT's model would be used to forecast area development factors and then use micro-economic land use theory to distribute the forecasted change. In order to accomplish this, land use data is needed with the resolution that LANDSAT can provide.

The potential benefits of LANDSAT as compared to hand collected data are numerous. LANDSAT data would greatly facilitate research efforts in terms of the costs and time saving as well as a greater sophistication of modeling when compared with the grossness of the data collection and accuracy now inherent in the model.

Present testing and evaluation of the model is limited to a seventeen county area in northeast Georgia. However, expansion of the model is anticipated as soon as its verification in this area is complete. Specific anticipated benefits of using the computer processed LANDSAT data for input to the model include:

- (1) The data are already available in computer compatible format, thus requiring little time and effort for input to the model.
- (2) The data can be referenced to any desired geographic coordinate system so that additional parameters can be included as desired.
- (3) Aggregation of the data by various civil boundaries is easily accomplished after referencing to a coordinate system.
- (4) Updating of the data base is easily accomplished when necessary.
- (5) No other source can provide data with this information content at an affordable cost.

Modeling efforts such as this will certainly be aided by having a source of land use data such as can be supplied by computer processing of LANDSAT CCT's. An analogy can be drawn here between present efforts at transportation, hydrologic and other modeling efforts that require land data and the early corporate attempts at producing workable management information systems (MIS).

A number of early attempts at producing workable MIS resulted in complete failure and the loss of many thousands or millions of dollars of

effort. Because each MIS was unique, it is not possible to assign a reason why all failed. However, a contributing factor in many of these failures was an inability to create an adequate data base that could be maintained efficiently and economically. In other words, the costs of maintaining the data base exceeded any benefits derivable from the information system which it supported.

Use of LANDSAT data in modeling efforts is likely to increase considerably because of the nature of the data. It is already in computer readable format. This makes it relatively inexpensive to work with the data before or after inputting to the model. For these reasons, we concluded that LANDSAT data will play a major role in many land-oriented data bases supporting planning models or other planning activities related to land use/land cover.

VI. SUMMARY AND CONCLUSIONS

In working with several agencies throughout this project, one need was emphasized regularly. This was the same need expressed by many respondents to the EES/MSFC questionnaire. More information concerning the capabilities of LANDSAT for land use/land cover mapping is eagerly desired. Particularly, more knowledge of the relationship of LANDSAT data products to planning agency requirements is sought.

Generally those individuals/agencies that are familiar with LANDSAT products are favorably disposed toward their use in operational projects being pursued. As expected, very few respondents had actually employed computer mapping of LANDSAT data in their work. However, slightly more than half of the respondents (52.5%) indicated that computer mapping could benefit their current and/or future projects.

The accuracies achieved with computer mapping approximate those achieved by other means as indicated in responses to the survey. The costs of computer mapping, however, are substantially less than most of the reported mapping efforts. It is possible, based on estimates by others, that even the EES cost estimates are too high. Certainly these figures should represent an upper limit on costs.

Based on the entire project results, a number of specific conclusions can be drawn. Among these are:

- (1) Computer mapping from LANDSAT data is fast and comparable in accuracy to many other mapping efforts.
- (2) The costs of computer mapping from LANDSAT data are substantially less than those of other methods.
- (3) Maps produced by these methods meet the operational requirements of many planning projects.
- (4) Level II accuracies are higher in rural than in urban areas and, thus, this technology is probably applicable to 95% of the land area of the southeast.
- (5) Level I mapping accuracies approach 100%.
- (6) There is a substantial desire for additional information related to LANDSAT capabilities and data products.

These conclusions are supported by the actual computer processing results achieved at the Douglas County test site, and by the responses to the questionnaires that were circulated. It is also certainly true that not all land use mapping efforts can be achieved by computer mapping from LANDSAT data. For these efforts, possible alternative methodologies and data sources were discussed in Section II. However, the majority of those responding to the survey favor use of this technology in their own efforts.

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APPENDIX A

The following is a list of respondents to the questionnaire used in preparing a portion of this report.

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